GRUMMAN AIRCRAFT ENGINEERING CORPORATION
AVOID VERBAL ORDERS

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SUBJECT: Program Alarms in Powered Descent - Apollo 11

The enclosed writeup presents the status of the investigation of the alarm codes that occurred during the Powered Descent Phase of the Apollo 11 mission. Included is a discussion of the alarm codes observed and their meaning and probable causes of the alarms.

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PROGRAM ALARMS IN POWERED DESCENT - APOLLO 11

DISCUSSION OF ALARM CODES OBSERVED AND THEIR MEANING

The LGC issued several Program Alarms subsequent to PDI. Examination of MSFN LGC digital downlist data presently available (July 22) indicates that there were 4 1202 alarms and 1 1201 alarm - See Table I for a tabulation of events during the powered portion of the landing as extracted from MSFN Tabs. These two classes of Alarm Codes are stored when the LGC's internal Job control routine, the EXECUTIVE, receives a request to establish another Job under its control when it is already controlling all the Jobs it has capacity for. Any Job activity in the LGC requires a small unshared set of errasable memory locations, called a core set. More complicated Jobs such as navigation or guidance computations, require a larger additional group of memory locations for Interpretive Mode computations. These memory sets are called Vector Accumulators or VAC areas. The EXECUTIVE has available for assignment to Jobs 8 core sets and 5 VAC areas. Any request to establish a Job after the 8 core sets are in use leads to the 1202 Alarm Code condition while a request to establish a Job requiring a VAC area after the 5 are assigned (availability of a core set is first checked) leads to AC1201.

These Alarm Codes then indicate overflows of the Job scheduling capacity of the LGC's internal Job control routine. When this condition is detected by the EXECUTIVE routine it transfers program control to an ALARM & ABORT routine which stores the appropriate code for display on the downlist and for possible display on the DSKY (by V5N9E), lights the PROG (Alarm) light on the DSKY, and transfers control to the FRESH START and RESTART routines. These are routines that were originally programmed to follow the LGC hardware activities resulting from a hardware detected restart. When the LGC goes to the RESTART routines from the ALARM & ABORT routines it is said to be doing a Software Restart, however.

The RESTART routines perform a general reinitialization of the machine rather similar to that done by a Fresh Start (V36E) and in fact using common coding. This includes clearing out the EXECUTIVE's list of currently scheduled Jobs. While a Fresh Start leaves the computer in a basic initial condition requiring loading and operator activity to bring up useful activity such as a Mission Program, the RESTART routines pass off to another routine which works in conjunction with the "restart protection" of the interrupted program (P63 and P64 in this case) to automatically put that program back into action at a logical point without loss of significant data such as the state vector and the PIPA's.

The LGC Flight Programs have been extensively "restart protected" which means that added into the mainline program coding are instructions which communicate to a service routine, called PHASE TABLE MAINTENANCE, information as to the progress of the mainline program's execution. The MAINTENANCE routine refers the "progress reports" to preplanned fixed coding or can accept "variable" information as to what activities should be started in case of a subsequent restart. Therefore the last sequence in a restart is a check of the Phase Tables and the activation of the routines then called for. The continued performance of the Primary Guidance Programs past the points of EXECUTIVE overflows was due to their restart protection.

There were also reports that an AC 1203 was experienced. Data available does not show any 1203's. The 1203 Alarm Code is quite similar to the 1201 and 1202. It indicates a scheduling overload of the WAITLIST, an LGC service routine that schedules time dependent activities called Tasks (as opposed to Jobs). When too many Tasks are attempted to be scheduled, a similar sequence to the EXECUTIVE overflow is started, leading ultimately to a Software Restart. The point of transfer into the ALARMS routine for all three of these Alarm Codes is called mnemonically "BAILOUT" so these alarms are somethimes called Bailout Alarms. They are equivalent to Software Restarts

DISCUSSION OF ACTIVITY OBSERVED ON MSFN DATA

The LGC in P63 commanded the Descent Engine ON at approximately 102^h 33^m 04^s GET to start PDI. About four and three quarters minutes later the LRALT light on the DSKY went out indicating Altitude Data Good from the LR. About 20 seconds later at 38^m 09^s the crew started to request a monitor of N68 (V16N68E) to show the difference between LR altitude and LGC altitude to determine if the LGC should start to incorporate this LR data. 12 seconds later and in the monitor, the first 1202 occurred. The GUIDO recognized that monitor verbs are a significant load on the computer and the Ground told the Crew that they would cover monitoring the altitudes for them. At 38^m 43^s the Crew entered V57 which tells the LGC to start incorporating LR data (if still good). However, at 38^m 49^s the Crew again requested V16N68. This would be normal procedure to determine the effect of incorporating LR data. The altitude difference in R3 should decrease. 12 seconds later another 1202 came up in the monitor. Note that the restart protection returns the normal program display (V6N63 in this case) "killing" the monitor. The Crew again requested V16N68 at 39^m 19^s. This time they exited the monitor after about 10 seconds and no alarm was experienced.

About 2 minutes later at 41^m 31^s P64 (high gate and the start of the visibility phase) was entered and nearly one minute later at 42^m 17^s a 1201 Alarm was experienced with no Crew DSKY activity. 24 sec. later there was a 1202 and 16 seconds later another 1202 again without CREW initiated DSKY activity. 24 seconds after that, at 43^m 21^s, they were in P66 and there were no more alarms.

Recapping, in P63 there were two alarms in each case after 12 seconds of a monitor verb. One other use of the monitor for 9 or 10 seconds did not induce an alarm.

P64 was used for 110 seconds. 46 seconds after entry there was a 1201, followed in 24 seconds by a 1202 and 16 seconds after that, a final 1202. There was no Crew DSKY activity related to these. P66 was free of alarms.

DISCUSSION OF CAUSES

The direct cause of the alarms was an overloading of the LGC's Job control routine. However, the programs are designed and tested so that this will not occur. Apparently an unaccounted for activity was going on in the computer that it could not handle along with extended use of monitor verbs in P63 and with only basic operation in P64. It has been determined that this unaccounted for activity related to the Rendezvous Radar CDU interface.

In order to make clearer how a data interface could affect Job scheduling the following discussion of the organization of the LGC is presented.

First, a basic design decision for the machine was to service the I/O ultimately thru the central processor (rather than by added hardware registers as is done in the AEA or by auxillary processors). There are three I/O classes based on frequency. Low frequency I/O is handled by several flip flop banks or "channels". The In channels are read by machine instruction under mailine program control as required to keep the program up on the status of the "discretes". Similarly, channels of flip flops can be set or written by program to provide output signals to the S/C and to other systems.

Medium frequency I/O requiring prompt recognition such as DSKY keystrokes is handled by a Priority Program Interrupt system that suspends certain (non-interrupt mode) types of coded programs to call up specific service routines.

The effects of the first class of I/O is rather directly apparent in the coding and is tested directly in program execution. The effect of the second class is deterministic subsequent to its initiation, but its occurrance is random in time and frequency in some cases.

The third class covers the high frequency serial data and the broad spectrum data that must not suffer losses such as the PIPA's and CDU's. These interfaces are serviced by an Involuntary Counter Interrupt system. Consider the case of a CDU input. The hardware of the computer recognizes each signal under its control. A plus trunnion angle pulse causes the Counter Interrupt system to stop the central processor's sequence generator at the end of the next coded instruction and to "snatch" one computer sub-instruction time - memory cycle time, MCT - to bring the contents of a specific erasable memory location assigned to the trunnion CDU into the adder. The contents are incremented by 1 and returned to E Memory. These E Memory locations are unfortunately referred to as counters though only schematically equivalent to the usual hardware counter. This activity occurs in one MCT, 11.72 micro seconds, and has no immediate outward effect on program flow such as a Program Interrupt does. However, the net effect of sustaining this interface on the central processor is a real time overhead burden. For example a constant 3KC rate of counter interrupts would mean a loss of 3.6% of real time available to the CP for other work.

In their All Digital Simulation testing of programs the MIT/IL directly accounts for the time loss due to all predictable counter interrupt activity. For example, if an angle is to change a certain amount this means there will be a corresponding time loss. To provide a pad and to account for unknown or undeterminate effects such as vibration effects on the IMU, tests are commonly run with an additional real time overhead of about 10 %. This is mnemonically referred to by the Simulator as TLOSS.

The other facet to the situation is that the LGC does not execute in a specific deterministic pattern in a way such as the AEA does. Rather it includes routines for self scheduling, the EXECUTIVE and the WAITLIST routines mentioned at the beginning. These routines handle the scheduling of (1) Jobs which have priority numbers and (2) Tasks which are activities that must be done at specific times. The result is hopefully a most efficient use of Central Processor time. In the periods of heaviest and most complex computer activity - powered descent and ascent - there is an intricate interplay of Tasks and Jobs to be controlled by the scheduling service routines. The guidance is based on recomputing every two seconds

navigation data, guidance commands (Throttle and steering), and converting the steering from guidance to DAP control outputs. At even more frequent rates data to drive the tape meters (alt. and alt. rate) and cross pointers must be computed. Since the computation work is done as Jobs, the arrangement is to have these Jobs requested of EXECUTIVE at specific times from Tasks scheduled and timed by the WAITLIST. The time scheduling is basically "open loop" with respect to whether the Job activity scheduled on the previous cycle was in fact completed. It is therefore conceivable that a Job might not get done (and so be removed from the EXECUTIVES's assignment list) before its scheduling Task came up again and asked the EXECUTIVE to schedule it. Multiple entries such as this, on their own or in conjunction with some heavy reandom request such as a monitor verb, could overload the EXECUTIVE as was experienced in this Flight.

Of course in the above the key question is why couldn't some Job(s) get done in time since they were designed and tested to be able to. There are several possibilities: (1) some Jobs might actually take longer than planned under some circumstances - certain solutions are obtained by iteration, for example. (2) since the EXECUTIVE puts the Jobs under its control on line in order of their priority number, it is possible that the relative priority assignments was not exactly optimum. Some higher frequency Job might not have a high enough priority to assure it would always be done in its period. (3) the amount of real time on the Central Processor available to mainline program might be significantly less than expected. Since these programs have been successfully tested stressed by a 10% TLOSS, it seems that the third possibility is most likely although the others could have contributed slightly.

<u>DISCUSSION OF THE RR - CDU - LGC INTERFACE.</u>
(See Figure 1.)

It has been determined that the RR-CDU-LGC interface was so configured during powered descent that the CDU's (shaft and trunnion) were receiving inputs (analog) signals that caused them to "slew" in an attempt to digitize the inputs. That is, they selected the 6.4 KC pulse train to drive the read counter and the LGC. For both channels this means 12,800 counter interrupts must be handled by the LGC per second. At about 12 μ secs each this takes about .15 seconds per second or a 15% real time overhead burden on CP time. This is 5% above the 10% TLOSS used in verification. P63 could not handle this in the presence of a monitor verb and P64 was marginal at this level (15%).

Figure 1 roughly schematizes the situation. When the RR panel switch is in LGC the RR resolvers receive their 800 cps reference from the Primary System. In SLEW or AUTO, however, they receive this reference from the ATCA. This voltage is frequency controlled by the Primary System through its control of the PCMTEA, but it is <u>not</u> phase controlled nor is it of the same magnitude wave form. These features of the resolver input to the CDU A/D converter section when not in LGC caused the CDU to "SLEW" (digitally). Note that neither RR ON/OFF or mode controls affect the CDU-LGC $\Delta\Theta$ interface. Also the RR breakers do not control the reference voltage connection from the ATCA to the resolvers. Data shows the RR was not in LGC during this period and also that the RR CDU Fail Discrete (CH30B07) was present. This discrete is set by a number of problems one of which is an excessive error condition.

The CDU's also contain digital to analog conversion capability and this capability of the two RR CDU's is used to permit the LGC to drive the cross pointers when the MODE SEL switch is in PGNS (CH30B06). This is commonly

referred to as the Display Inertial Data Mode. If the RR is in LGC but not locked on, the output of the D to A converter goes to the radar so it would be possible to try to designate the antenna with cross pointer inertial velocity data (undesireable). When in SLEW or AUTO this "false" designate possibility does not exist. For this reason the RR was in the AUTO mode for LM-5.

FCI LAB TESTING

The FCI Laboratory does not have an RR antenna with the resolvers or substitude servos with resolvers. It does have the hardware CDU's, which are a part of the CDU assembly along with the inertial channels. The FMES (Environment) computers and interface equipment supply angle information at the LGC pulse ($\Delta\theta$) interface, substituting for the CDU's. This data is normally processed by the Involuntary Counter Interrupt control. In order to simulate the actual condition that occurred in descent, one of the following changes could be made: (1) Make an analog circuit to input the A/D end of the CDU's with a signal of like characteristics as developed by the RR resolvers with the ATCA supplied reference. (2) Put 6.4 KC on the present interfaces. In order to check out changes in the Flight Program for Apollo 12, LUMINARY 1B, the first arrangement will be required.

LUMINARY 1B, which will be tested in the FCI lab shortly, contains two changes pertinent to the subject at hand. One, covered by PCR 814, provides for a modified V57 which incorporates a display of N68, thereby doing away with any need for a monitor verb. MIT/IL estimated in the PCR a 5% computer time saving. The second was a change resulting from Apollo 11, PCR 848, which provides for issuing RR CDU ZERO's while the RR is not in LGC. This CDU mode should have the effect of preventing any digitizing of an input to the CDU. In order to properly test this arrangement the CDU-LGC interface should be in, indicating we need an arrangement inputing the analog end of the CDU's.

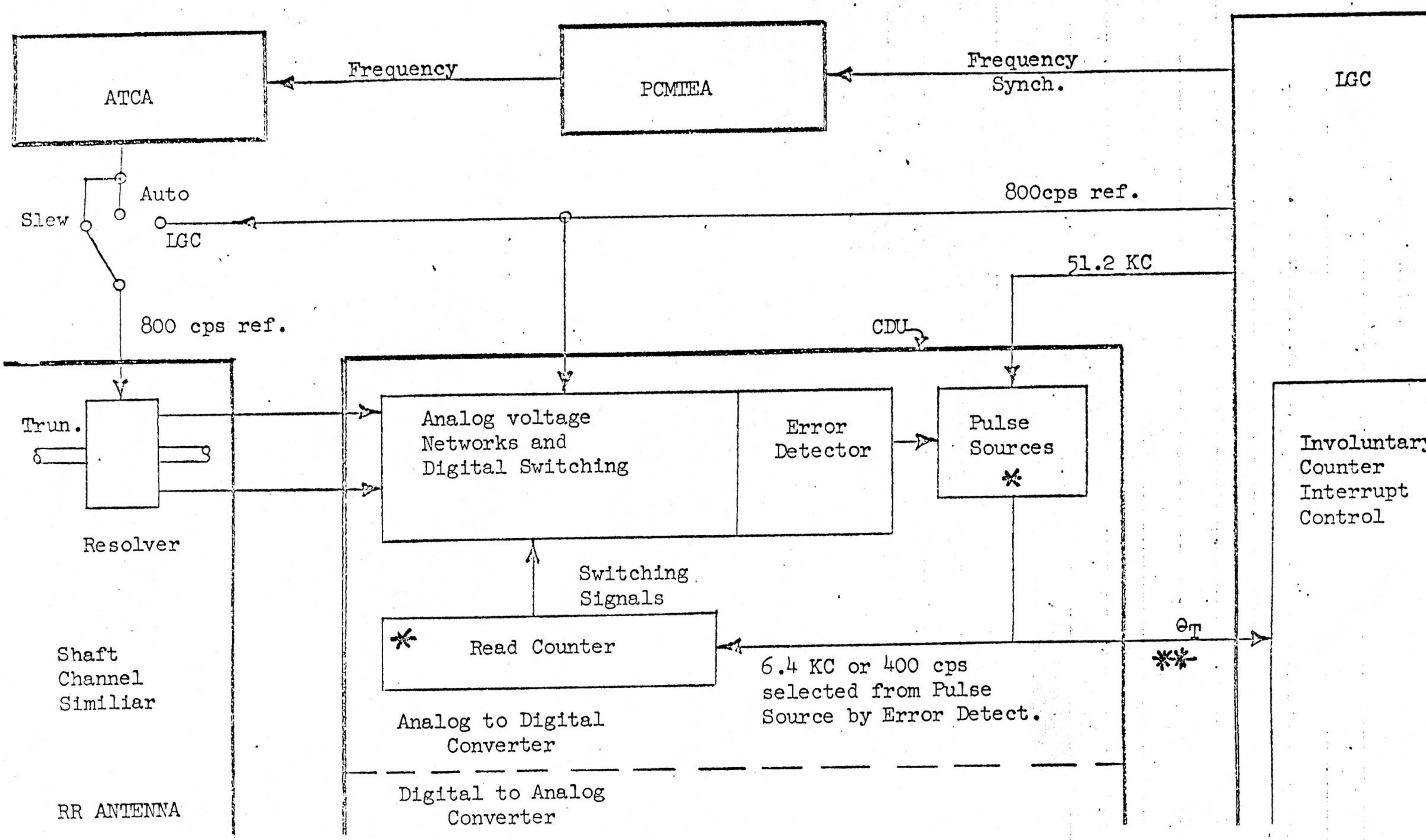
Note that regarding LR data Ch33 indicates LR ALT & VEL Data Good at $37^m\ 49^s$ both dropout at $44^m\ 9^s$ back at $44^m\ 19^s$; both out at $44^m\ 57^s$ and back at $45^m\ 01^s$ and both out at $45^m\ 39^s$. There are many time gaps in these bi levels.

TABLE I

	GET						
	102^h	33^m	04^s	ENGINE ON	(03^s CH11B13)		P63
$\delta\ 4^m 35^s$		37	37-49	LRALT light out DSPTAB + 11D B05 H=37672'			
		38	09	V16 NBB			
		38	11	V16 N68	-2771'		
		38	21	1202	(FAIL REG)	(V16N68) PROG lt. at 23^s DSPTAB + 11D B09	
		38	43	V57			
			49	V16NBB			
				V16N68	(-1772)		
		39	01	VBBNBB	1202 (FAILREG)	PROG lt.	
		39	19	V16N63			
				V16N68	-60'	No AC	
		39	25	V16N68	-98'		
			29	V06N63			
$\delta\ 8^m 27^s$ →		41	31	F V06N64		H = 7129'	P64
				(LR switched positions between $41^m\ 29^s$ and 35^s)			
		42	17	1201	(FAILREG)	PROGlt.	(H=3000')
		42	25-33	PRO'd to get LPD capability		FWD 6 B06	
		42	41	1202 (FAILREG)		PROGlt at 43^s	
		42	57	1202 (FAILREG)		no data on PROG lt.	
	102^h	42^m	55^s	According to Bi Level Tabs for these times			P64
		43	07	Neil went out of detent with a - EL (LPD) signal (CH31B02). New site is beyond present landing site. At $43^m\ 05^s$ there is 48^s of LPD time left (about 68^s to P65 - low gate); an LPD ⋌ of 33°; $\dot{H}$ - -21.9fps; H = 684 ft.			
		43	21	Rate of Descent Program Selected (by use of DES RATE Switch)			P66
				Horizontal Vel +60.3 fps; $\dot{H}$ = -10.0 fps; H = 410 ft			
	102^h	45^m	40^s	Touchdown Hor. Vel +4.9 fps; $\dot{H}$ = -1.2 fps; H = 13 ft			

Touchdown time is estimated from the DSPTAB Tabs of R1,2,3 and Tabs of the DELV's.

Parameter values noted on this table are from R1,2,3.



* RR CDU ZERO Mode (Presence of Ch12 B01) holds the Read Counter Reset and disables gating out of pulses to the Read Counter and the LGC

FIG 1. Rough Schematic of RR-CDU-LGC Interface.

** Our RR Shaft and Trunnion angle data from FMES replaces the normal CDU output here.